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The

National Shipbuilding

Research Program

EVALUATION OF THE FILLET WELD SHEAR STRENGTH OF FLUX CORED ARC WELDING ELECTRODES

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FORWARD

This report presents the results of a project initiated by SP-7, the Welding R&D Panel of the Ship Production Committee of the Society of Naval Architects and Marine Engineers. The project was financed through a cost sharing contract between the U. S. Maritime Administration and Ingalls Shipbuilding, Incorporated. The principal objective was to develop data on the longitudinal and transverse shear strength of flux cored arc welding filler metals. Consistently higher shear strength properties of flux core over solid wire and conventional electrodes would provide a basis for implementing smaller, more cost effective fillet weld requirements in ship structures.

Flux core filler metals for high yield strength steels (for example, HY-80 and HSLA 80) were qualified for primary hull structures in the early '80's. Some of the early work supported by the National Shipbuilding Research Program contributed to the development and qualification of flux core wire for shipbuilding. The cost savings have been significant. Weld deposition rates of more than 30% increase over solid wire Metal Inert Gas welding have been realized, especially in vertical and overhead welding.

In addition greater use of flux core welding has reduced weld repairs caused by loss of shield gas due to air movement in open areas of the shipyard.

A reduction of fillet weld size would be yet another spin-off benefit of shipyard use of flux cored weld wire.

This project answers many of the questions which have been raised about root penetration and shear strength of fillet welds. The data supports a proposal *to revise the U. S. Navy design document to permit smaller fillet welds in structures welded with steels below 80 KSI yield but not the higher strength materials.*

When implemented, even the 1/16" reduction in weld sizes indicated by the project results will produce significant reductions in welding costs for both commercial and military ship fabrication.

The project was *conducted under the leadership of Lee Kvidahl both as Chairman of the SP-7 Panel, and as Manager of the Ingalls Welding Engineering Laboratory. The Lead Engineer was Russ W. McClellan who has reported project results to the American Welding Society and also prepared this much more detailed report.*

O. J. Davis
SP-7 Program Manager

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ABSTRACT

This paper presents results of a research project conducted by the Welding Engineering Department at Ingalls Shipbuilding. The primary effort of this project was directed towards the development of shear strength data for flux cored arc (FCAW) welding electrodes. The current welding design document for U. S. Navy construction, MIL-STD-1628[1], does not include fillet weld shear strength values for this widely used process. Presently, the equivalent shielded metal arc (SMAW) welding electrode values are used for design purposes.

The project evaluated the longitudinal and transverse shear strength of MIL-71 T1-HY[2] and MIL-10I TC/TM[3] electrodes. Testing of welds made with MIL-71 T1-HY FCAW electrodes revealed higher fillet weld shear strength values when compared to the equivalent SMAW data. As a result, economic savings may be realized with the use of potentially smaller fillet welds. The MIL-101 TC/TM values were equivalent to a comparable SMAW electrode.

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I. INTRODUCTION AND OBJECTIVES

In a continuing effort to become more cost effective, U. S. shipyards are implementing a higher percentage of semi-automatic welding processes. Effective shipbuilding fabrication requires the use of efficient, economical welding methods while maintaining high levels of quality. A large percentage of this welding is performed out of position. The FCAW process is one of the most efficient welding processes for high deposition and quality in out of position fabrication.

FCAW is not a new development. Until recently, process constraints due to electrode characteristics and weldability restricted the applications of FCA W for shipbuilding. However, during the past several years, the filler material manufacturing industry has performed much research and development work that has resulted in flux cored electrodes with excellent strength and toughness which can be welded in all positions. Improvement in the manufacturing process controls and raw material selection ensures consistent high quality which provide the necessary mechanical properties to expand FCAW applications to include higher strength steels such as HY-80[4] and HSLA-80[5].

In ship design, shear strength is emphasized when determining fillet weld size requirements. The joint efficiency is based upon the load carrying capacity of the weaker member and the shear strength of the filler metal. The current design document, MIL-STD-1628, does not include the fillet weld shear strength values for FCAW electrodes. Presently, the comparable SMAW electrode values are used for design purposes.

This project was undertaken because of the large amount of fillet welds in a typical ship design. It is common for 90% of the joints to be fillet welds for structural connections. This represents several miles of weld length for each ship.

Two FCAW electrodes, MIL-71TI-HY and MIL-101-TC/TM, were evaluated in this series of tests. Their respective chemistries are noted in Table 1. These electrodes typically have higher tensile strength values and have superior penetration capabilities than their respective SMAW equivalents, namely the MIL-7018-M6 and MIL-1OO1 8-Ml [7] covered electrodes. The criteria from MIL-STD-1628 does not consider the possible effects that these characteristics may have on the joints shear mechanics which may result in higher fillet weld shear values. The effect may be significant enough to warrent reduction of required fillet weld sizes in the design stage of ships with no reduction in structural strength (See Figure 1). Primary benefits to be expected from reduction in fillet weld size requirements are significant weight reductions and reduction in production costs in both manhours and materials.

Shear specimen preparation, testing, and evaluation are dealt with in depth in the succeeding text. All laboratory efforts were conducted in strict accordance with ANSI/AWS B4. 0-85[8] in an attempt to produce repeatable data.

TABLE 1

FCAW ELECTRODE CHEMISTRIES

	MIL-71T1-HY	MIL-101-TC/TM
C	0.12	0.10
Mn	0.50-1.75	0.50-1.50
Si	0.90	0.60
Ph	0.030	0.020
S	0.030	0.017
Ni	0.50	1.30-3.75
Cr	0.20	0.20
Mo	0.30	0.50
V	0.05	0.05
Cu	0.20	0.06

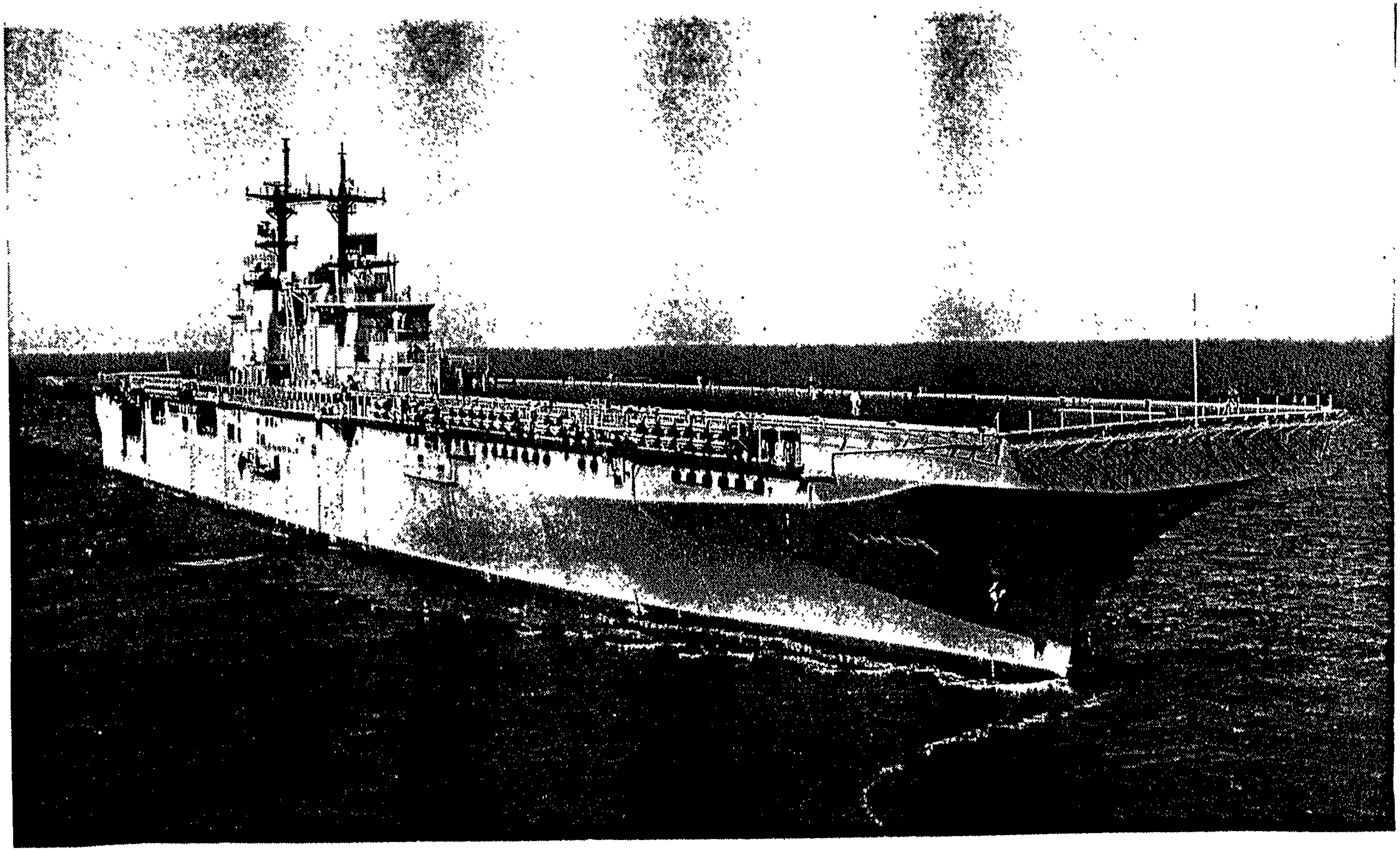


Figure 1. U.S. Navy Multipurpose Amphibious Ship, USS WASP (LHD 1)

II. <u>LABORATORY EFFORT</u>

Longitudinal and transverse shear specimens were prepared with 0.052" (1.3mm) diameter FCAW electrodes. The electrodes were provided by various manufacturers and tested with both a 75% argon/25% CO_2 shielding gas mixture and a shielding of straight welding grade CO_2. Specimens were prepared from HY-80, HSLA-80, and AH-36[9] steels. Using identical weld parameters (235 amps, 25 volts, 15 ipm) and an automatic tracking system, lab technicians prepared 1/4" (6. 4mm) single pass fillets and 3/8" (9. 5mm) three pass fillets. A total of 96 tests were conducted with the purpose of developing a broad data base.

Each specimen was positioned in a tensile machine where the load was applied parallel to the axis of the specimen (See Figures 2 and 3). Records were kept documenting the maximum force needed to produce each shear failure, actual shear lengths, fillet sizes, throat dimensions and estimated angle of shear.

After measuring the fillet sizes, the theoretical throat was calculated and used to determine the specimen's shear strength as specified in ANSI/AWS B4.0-85 (See Figure 4).

To conclude all laboratory efforts, six longitudinal and six transverse specimens were the subject of a metallographic analysis. Shown photographs (Figures 9 through 20) clearly reveal arc penetrating characteristics and the angle of shear at which failure occurred.

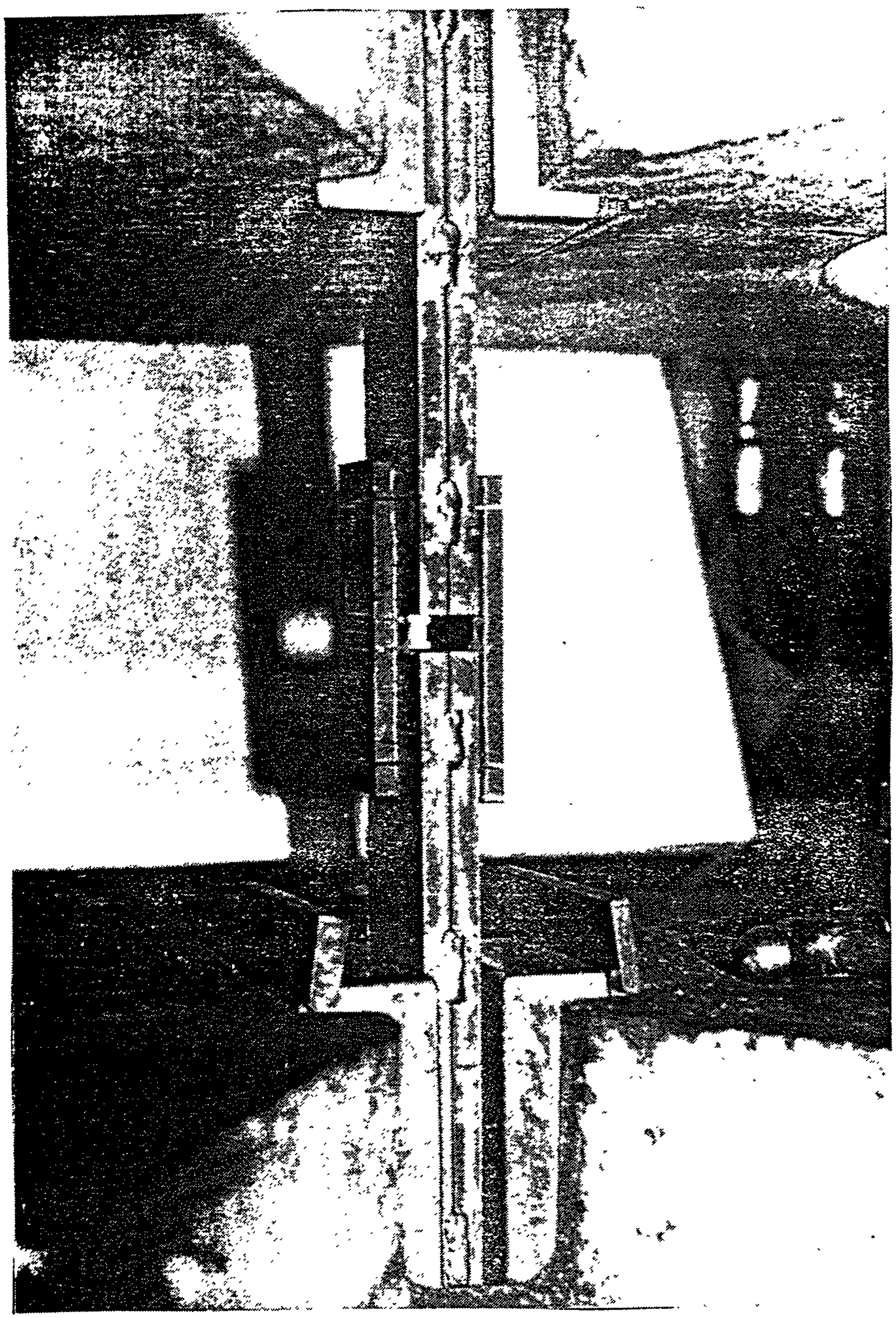


Figure 2. Longitudinal Shear Specimen

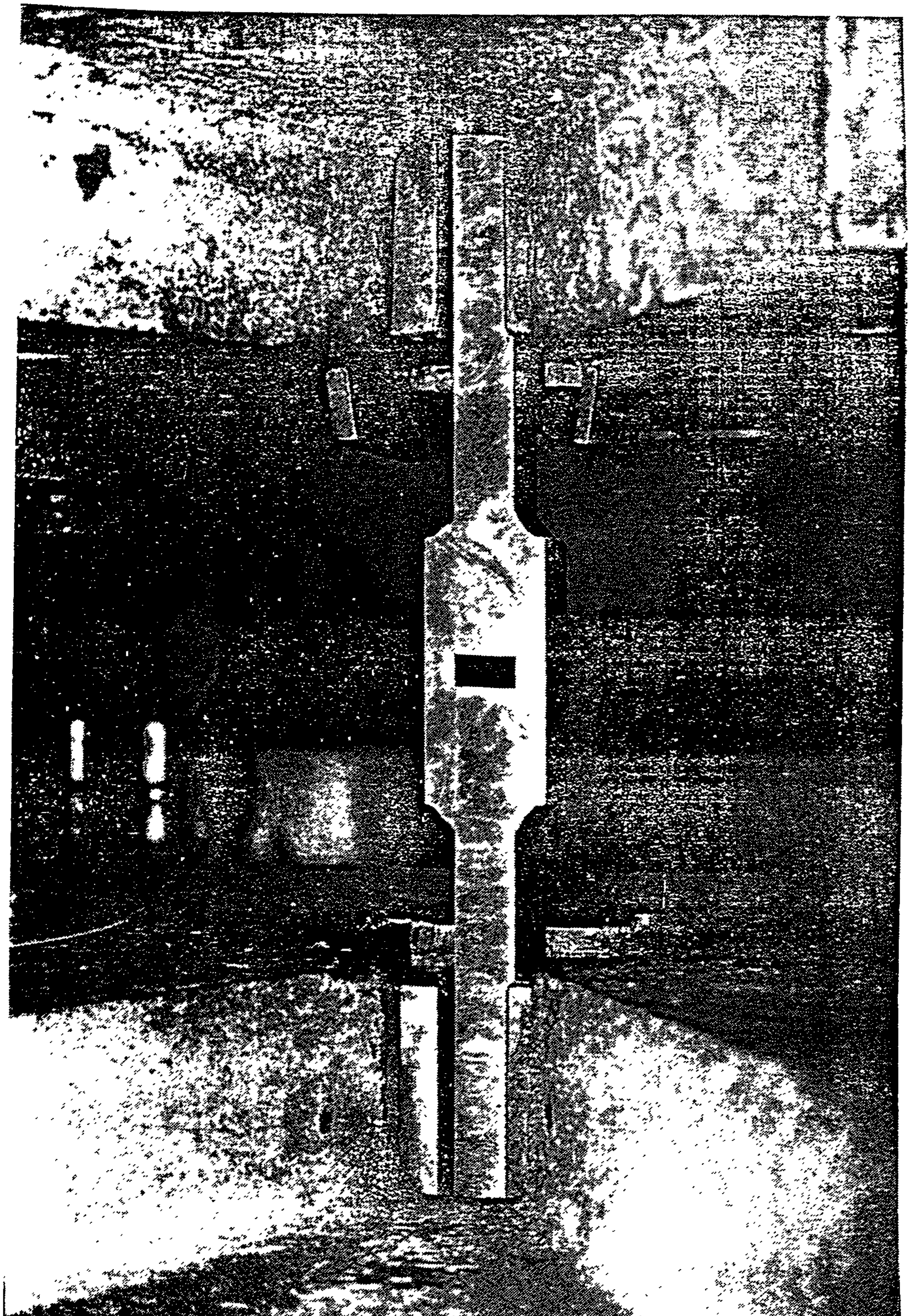
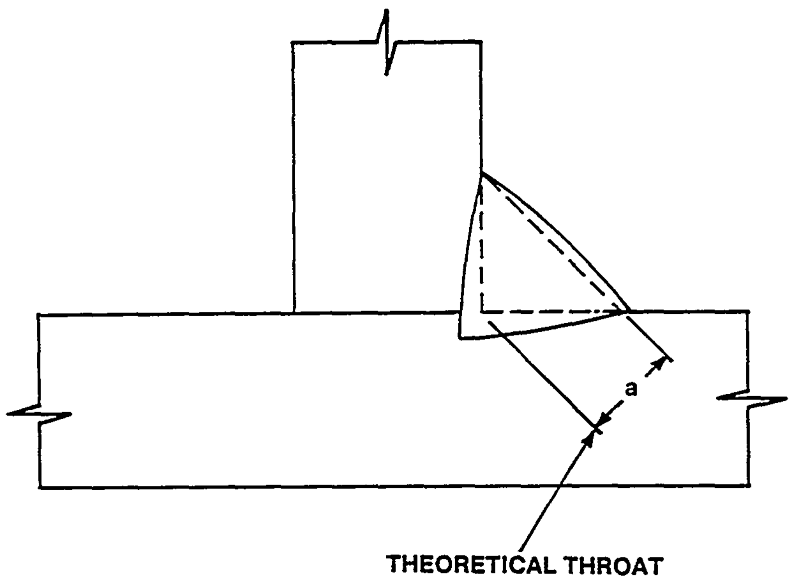


Figure 3. Transverse Shear Specimen



$$s = \frac{p}{l \times a}$$

WHERE:

p Load
l = Total Length of Fillet Weld Sheared
a = Theoretical Throat Dimension
s = Shear Strength of Weld

Figure 4. Shear Strength Calculation (ANSI/AWS B4.0-85)

III. RESULTS

Results of the longitudinal and transverse shear tests are exhibited in Tables 2 through 7. The data is segregated into filler wire, shield gases, and fillet weld sizes. Tables 8 and 9 list the averages for each set of values.

Following the destructive tests, each specimen was examined and its angle of shear estimated. The tables contain these estimations and Figures 5 and 6 exhibit the observed 45° and 22.5° shear angles.

To evaluate the weld penetration, a micrographic analysis was conducted on select transverse and longitudinal specimens. Figures 7 and 8 are drawings showing the cross-sectional areas relevant to the metallography in Figures 9 through 20.

The succeeding tables contain data noted and developed during the fabrication and destructive evaluation of shear specimens. The following is a column by column explanation of the information included in the tables:

1. *Specimen number as designated during lab testing.*

2. *Specimens were tested using 75% Argon/25% CO_2 mixed gas shielding and a straight CO_2 shielding.*

3. *Electrodes were evaluated from two different wire manufacturers.*

4. *Targeted fillet size during fabrication of shear specimens.*

5. *Actual measured fillet sizes.*

6. *Calculated throat assuming a 45° shear angle as required by ANSI/AWS B4.0-85.*

7. *Shear load in pounds per linear inch as determined by tensile testing.*

8. *Shear strength in PSI assuming a 45° shear angle as required by ANSI/AWS B 4.0-85.*

9. *Actual shear angle visually determined following destructive tests.*

10. *Calculated throat assuming a 22.5° shear angle (transverse only).*

11. *Shear strength in PSI assuming a 22.50 shear angle (transverse only).*

12. *Shear strength difference between assumed shear angles of 45° and 22.5° (transverse only).*

TABLE 2

LONGITUDINAL SHEAR DATA

BASE MATERIAL--AH-36, FILLER MATERIAL--71T1-HY

1	2	3	4	5	6	7	8	9
SPECIMEN	SHIELD GAS	WIRE MFG	FILLET SIZE	ACTUAL FILLET SIZE	THEORET THROAT	SHEAR LOAD	SHEAR STRENGTH	SHEAR ANGLE
1A	75/25	A	1/4"	.270	.191	11,916	62,391	45°
2A	75/25	A	1/4"	.250	.177	12,436	70,260	45°
3A	75/25	B	1/4"	.265	.187	11,046	59,070	45°
4A	75/25	B	1/4"	.250	.177	11,571	65,373	45°
5A	CO_2	A	1/4"	.265	.187	11,951	63,909	45°
6A	CO_2	A	1/4"	.250	.177	12,018	67,896	45°
7A	CO_2	B	1/4"	.250	.177	11,864	67,030	45°
8A	CO_2	B	1/4"	.250	.177	12,137	68,569	45°
9A	75/25	A	3/8"	.375	.265	18,476	69,721	45°
10A	75/25	A	3/8"	.360	.256	16,498	64,820	45°
11A	75/25	B	3/8"	.350	.250	18,407	74,389	45°
12A	75/25	B	3/8"	.375	.265	19,950	75,279	45°
13A	CO_2	A	3/8"	.375	.265	17,517	66,102	45°
14A	CO_2	A	3/8"	.365	.258	18,718	72,547	45°
15A	CO_2	B	3/8"	.360	.255	18,650	73,275	45°
16A	CO_2	B	3/8"	.335	.237	17,664	74,580	45°

TABLE 3
LONGITUDINAL SHEAR DATA
BASE MATERIAL-HY-80, FILLER MATERIAL--101TC/TN

1 SPECIMEN	2 SHIELD GAS	3 WIRE MFG	4 FILLET SIZE	5 ACTUAL FILLET SIZE	6 THEORET THROAT	7 SHEAR LOAD	8 SHEAR STRENGTH	9 SHEAR ANGLE
17A	75/25	A	1/4"	.270	.191	12,438	65,119	45°
18A	75/25	A	1/4"	.260	.184	12,007	65,255	45°
19A	75/25	B	1 /4"	.260	.184	11,953	64,961	45°
20A	75/25	B	1/4"	.275	.194	12,093	62,201	45°
21A	$C0_2$	A	l/4"	.250	.177	13,065	73,815	45°
22A	$C0_2$	A	1 /4"	.260	.184	12,936	70,305	45°
23A	VOID							
24A	$C0_2$	B	1/4"	.250	.177	13,443	75,950	45°
25A	75/25	A	3/8"	.350	.250	19,430	78,521	45°
26A	75/25	A	3/8"	.360	.255	19,240	75,272	45°
27A	75/25	B	3/8"	.365	.260	20,154	78,101	45°
28A	75/25	B	3/8"	.370	.262	19,577	74,720	45°
29A	$C0_2$	A	3/8"	.345	.244	21,127	86,615	45°
30A	$C0_2$	A	3/8"	.355	.250	20,226	80,585	45°
31A	$C0_2$	B	3/8"	.340	.240	20,865	86,793	45°
32A	$C0_2$	B	3/8"	.370	.262	20,291	77,447	45°

TABLE 4
LONGITUDINAL SHEAR DATA
BASE MATERIAL--HSLA-80, FILLER MATERIAL--101TC/TH

1 SPECIMEN	2 SHIELD GAS	3 MIRE MFG	4 FILLET SIZE	5 ACTUAL FILLET SIZE	6 THEORET THROAT	7 SHEAR LOAD	8 SHEAR STRENGTH	9 SHEAR ANGLE
33A	75/25	A	1/4"	.250	.177	13,905	78,560	45°
34A	75/25	A	1/4"	.225	.160	12,730	80,022	45°
35A	75/25	B	1/4"	.250	.177	11,952	67,525	45°
36A	75/25	B	1/4"	.250	.177	11,597	65,518	45°
37A	CO_2	A	1/4"	.265	.187	15,160	80,911	45°
38A	CO_2	A	1/4"	.250	.177	14,808	83,663	45°
39A	CO_2	B	1/4"	.245	.173	11,622	67,178	45°
40A	CO_2	B	1/4"	.245	.173	11,885	68,697	45°
41A	75/25	A	3/8"	.360	.255	19,404	76,245	45°
42A	75/25	A	3/8"	.375	.265	18,933	71,445	45°
43A	75/25	B	3/8"	.375	.265	19,631	74,079	45°
44A	75/25	B	3/8"	.355	.250	19,371	77,182	45°
45A	CO_2	A	3/8"	.370	.262	19,421	74,238	45°
46A	CO_2	A	3/8"	.400	.283	18,772	66,332	45°
47A	CO_2	B	3/8"	.350	.248	19,123	77,108	45°
48A	CO_2	B	3/8"	.360	.255	19,641	77,025	45°

TABLE 5
TRANSVERSE SHEAR DATA
BASE MATERIAL--AH-36, FILLER MATERIAL--71T1-HY

1	2	3	4	5	6	7	8	9	10	11	12
SPECIMEN	SHIELD GAS	WIRE MFG	FILLET SIZE	ACTUAL FILLET SIZE	45° THEORET THROAT	SHEAR LOAD	45° SHEAR STRENGTH	SHEAR ANGLE	22.5° THEORET THROAT	22.5° SHEAR STRENGTH	SHEAR STRENGTH DIFFERENCE
1B	75/25	A	1/4"	.270	.191	18,875	98,874	20-25°	.207	91,184	8.4%
2B	75/25	A	1/4"	.280	.198	20,000	101,010	20-25°	.214	93,340	8.2%
3B	75/25	B	1/4"	.320	.230	21,333	94,295	20-25°	.245	87,127	8.2%
4B	75/25	B	1/4"	.270	.191	17,750	92,985	20-25°	.207	85,919	8.2%
5B	CO_2	A	1/4"	.280	.198	19,211	97,042	20-25°	.214	89,771	8.1%
6B	CO_2	A	1/4"	.230	.163	17,105	105,192	20-25°	.176	97,196	8.2%
7B	CO_2	B	1/4"	.270	.191	21,750	113,940	20-25°	.207	105,072	8.4%
8B	CO_2	B	1/4"	.275	.194	22,308	114,737	20-25°	.210	106,229	8.0%
9B	75/25	A	3/8"	.365	.258	24,750	95,910	20-25°	.279	88,710	8.1%
10B	75/25	A	3/8"	.350	.248	28,169	113,837	15-20°	.268	105,108	8.3%
11B	75/25	B	3/8"	.400	.283	30,000	106,082	15-20°	.306	98,039	8.2%
12B	75/25	B	3/8"	l 375	.265	26,667	100,581	7-12°	.287	92,916	8.3%
13B	CO_2	A	3/8"	.350	.248	25,946	104,853	7-12°	.268	96,813	8.3%
14B	CO_2	A	3/8"	.400	.283	27,692	97,852	20-25°	.306	90,497	8.1%
15B	CO_2	B	3/8"	.375	.265	29,305	110,535	10-15°	.287	102,108	8.3%
16B	CO_2	B	3/8"	.360	.255	28,378	111,498	10-15°	.276	102,819	8.4%

TABLE 6
TRANSVERSE SHEAR DATA
BASE MATERIAL--HY-80, FILLER MATERIAL--101TC/TH

1	2	3	4	5	6	7	8	9	10	11	12
SPECIMEN	SHIELD GAS	WIRE MFG	FILLET SIZE	ACTUAL FILLET SIZE	45° THEORET THROAT	SHEAR LOAD	45° SHEAR STRENGTH	SHEAR ANGLE	22.5° THEORET THROAT	22.5° SHEAR STRENGTH	SHEAR STRENGTH DIFFERENCE
17B	75/25	A	1 /4"	.270	.191	19,750	103,463	20-25°	.207	95,411	8.4%
18B	75/25	A	1/4"	.250	.177	20,000	113,154	20-25°	.192	104,167	8.6%
19B	75/25	B	1/4"	.330	.233	20,811	89,198	20-25°	.252	82,583	8.0%
20B	75/25	B	1/4"	.290	.205	21,918	106,900	20-25°	.222	98,730	8.3%
21B	CO_2	A	1/4"	.275	.194	20,811	107,038	20-25°	.210	99,100	8.0%
22B	CO_2	A	1/4"	.250	.177	22,632	128,043	20-25°	.192	117,875	8.6%
23B	CO_2	B	1/4"	.305	.216	21,538	99,883	20-25°	.234	92,043	8.5%
24B	CO_2	B	1/4"	.285	.202	22,676	112,539	20-25°	.219	103,543	8.7%
25B	75/25	A	3/8"	.400	.283	31,282	110,537	40-45°	.306	102,229	8.1%
26B	75/25	A	3/8"	.395	.279	30,650	109,750	20-25°	.302	101,490	8.1%
27B	75/25	B	3/8"	.355	.250	27,317	108,840	5-10°	.271	100,801	8.0%
28B	75/25	B	3/8"	.395	.279	33,514	120,006	5-10°	.302	110,974	8.1%
29B	CO_2	A	3/8"	.395	.279	32,368	115,906	20-25°	.302	107,179	8.1%
30B	CO_2	A	3/8"	.400	.283	30,000	106,082	20-25°	.306	98,039	8.2%
31B	CO_2	B	3/8"	.400	.283	28,158	99,568	5-10°	.306	92,120	8.1%
32B	CO_2	B	3/8"	.390	.276	29,872	108,337	15-20°	.299	99,906	8.4%

TABLE 7
TRANSVERSE SHEAR DATA
BASE MATERIAL--HSLA-80, FILLER MATERIAL--101TC/TH

1 SPECIMEN	2 SHIELD GAS	3 WIRE MFG	4 FILLET SIZE	5 ACTUAL FILLET SIZE	6 45° THEORET THROAT	7 SHEAR LOAD	8 45° SHEAR STRENGTH	9 SHEAR ANGLE	10 22.5° THEORET THROAT	11 22.5° SHEAR STRENGTH	12 WEAR STRENGTH DIFFERENCE
33B	75/25	A	1/4"	.260	.184	18,750	102,002	20-25°	.199	94,221	8.3%
34B	75/25	A	1/4"	.275	.194	20,000	102,867	20-25°	.210	95,238	8.0%
35B	75/25	B	1/4"	.280	.198	18,519	93,547	20-25°	.214	86,537	8.1%
36B	75/25	B	1/4"	.255	.180	19,512	108,230	20-25°	.195	100,062	8.2%
37B	$C0_2$	A	1 /4"	.275	.194	19,351	99,528	20-25°	.210	92,148	8.0%
38B	$C0_2$	A	1/4"	.255	.180	17,037	94,500	26-30°	.195	87,369	8.2%
39B	$C0_2$	B	1/4"	.275	.194	18,250	93,866	26-30°	.210	86,905	8.0%
40B	$C0_2$	B	l/4"	.265	.187	18,974	101,275	20-25°	.202	93,931	7.8%
41B	75/25	A	3/8"	.410	.290	27,000	93,145	20-25°	.314	85,987	8.3%
42B	75/25	A	3/8"	.405	.286	26,000	90,803	20-25°	.310	83,871	8.3%
43B	75/25	B	3/8"	.380	.269	27,000	100,499	20-25°	.291	92,784	8.3%
44B	75/25	B	3/8"	.400	.283	28,684	101,358	20-25°	.306	93,739	8.1%
45B	$C0_2$	A	3/8"	.385	.272	26,750	98,275	20-25°	.294	90,986	8.0%
46B	$C0_2$	A	3/8"	.400	.283	26,750	94,590	20-25°	.306	87,418	8.2%
47B	$C0_2$	D	3/8"	.400	.283	26,154	92,482	20-25°	.306	85,471	8.2%
48B	$C0_2$	B	3/8"	.375	.265	24,500	92,409	5-10°	.287	85,366	8.3%

TABLE 8

AVERAGE LONGITUDINAL SHEAR STRENGTH VALUES

BASE MATERIAL	SHIELD GAS	(PSI) SHEAR STRENGTH
AH36 (MIL-71T1-HY)	CO_2	69,239
	75 Ar/25 CO_2	67,663
	Average	68,451
HY-80 (MIL-101TC/TM)	CO_2	78,787
	75 Ar/25 CO_2	70,519
	Average	74,378
HSLA-80 (MIL-101TC/TM)	CO_2	74,394
	75 Ar/25 CO_2	73,822
	Average	74,108

TABLE 9
AVERAGE TRANSVERSE SHEAR STRENGTH VALUES

MATERIAL BASE	SHEAR ANGLE	SHIELD GAS	(PSI) SHEAR STRENGTH
AH36 (MIL-71T1-HY)	45°	CO_2	106,956
		75 Ar/25 CO_2	100,447
		Average	103,701
AH36 (MIL-71T1-HY)	22.5°	CO_2	98,813
		75 Ar/25 CO_2	92,793
		Average	95,803
HY-80 (MIL-101TC/TM)	45°	CO_2	109,675
		75 Ar/25 CO_2	107,731
		Average	108,702
HY-80 (MIL-101TC/TM)	22.5°	CO_2	101,226
		75 Ar/25 CO_2	99,548
		Average	100,387
HSLA-80 (MIL-101TC/TM)	45°	CO_2	95,866
		75 Ar/25 CO_2	99,056
		Average	97,461
HSLA-80 (MIL-101TC/TM)	22.5°	CO_2	88,699
		75 Ar/25 CO_2	91,555
		Average	90,127

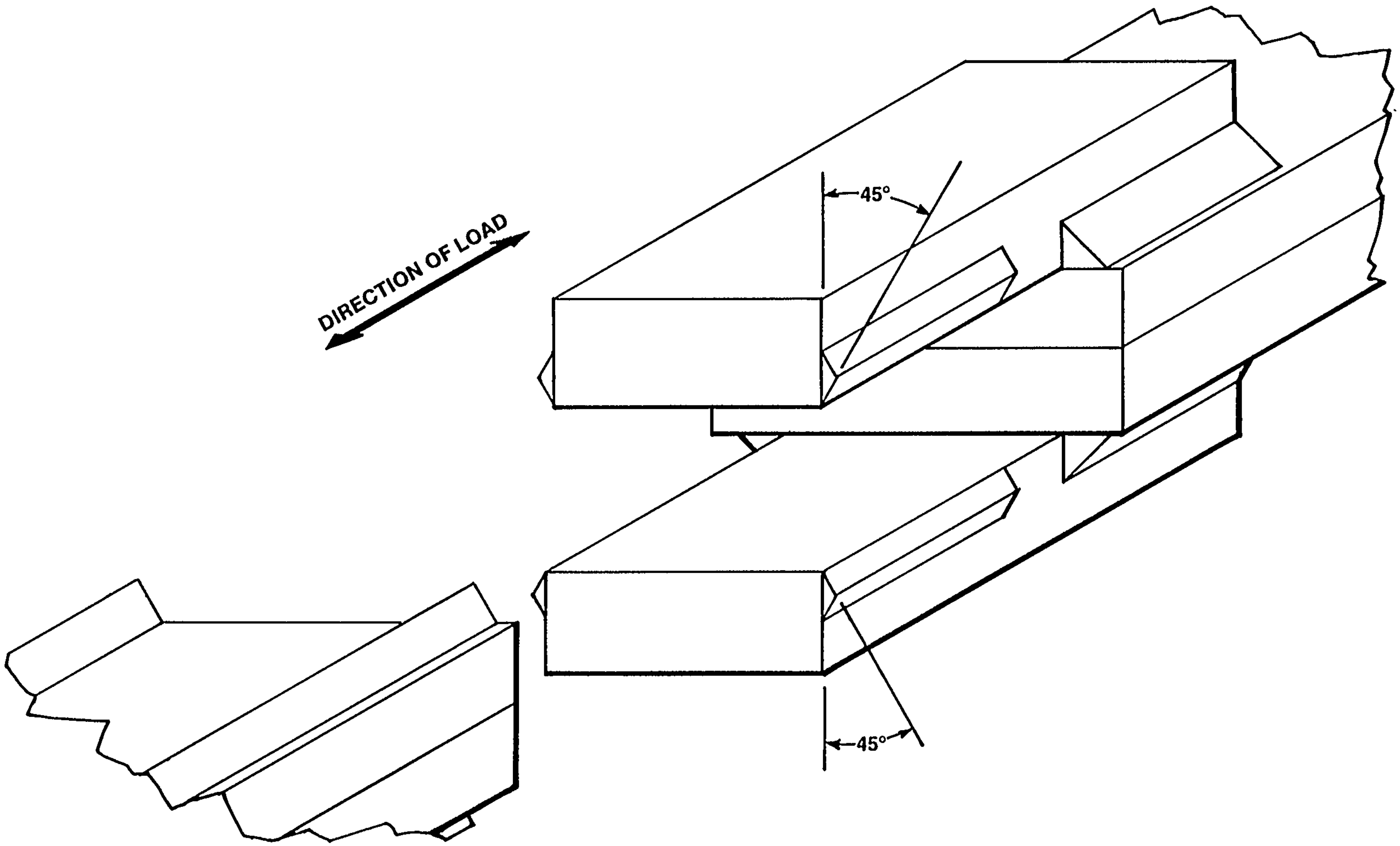


Figure 5. Typical Longitudinal Shear Failure Angle

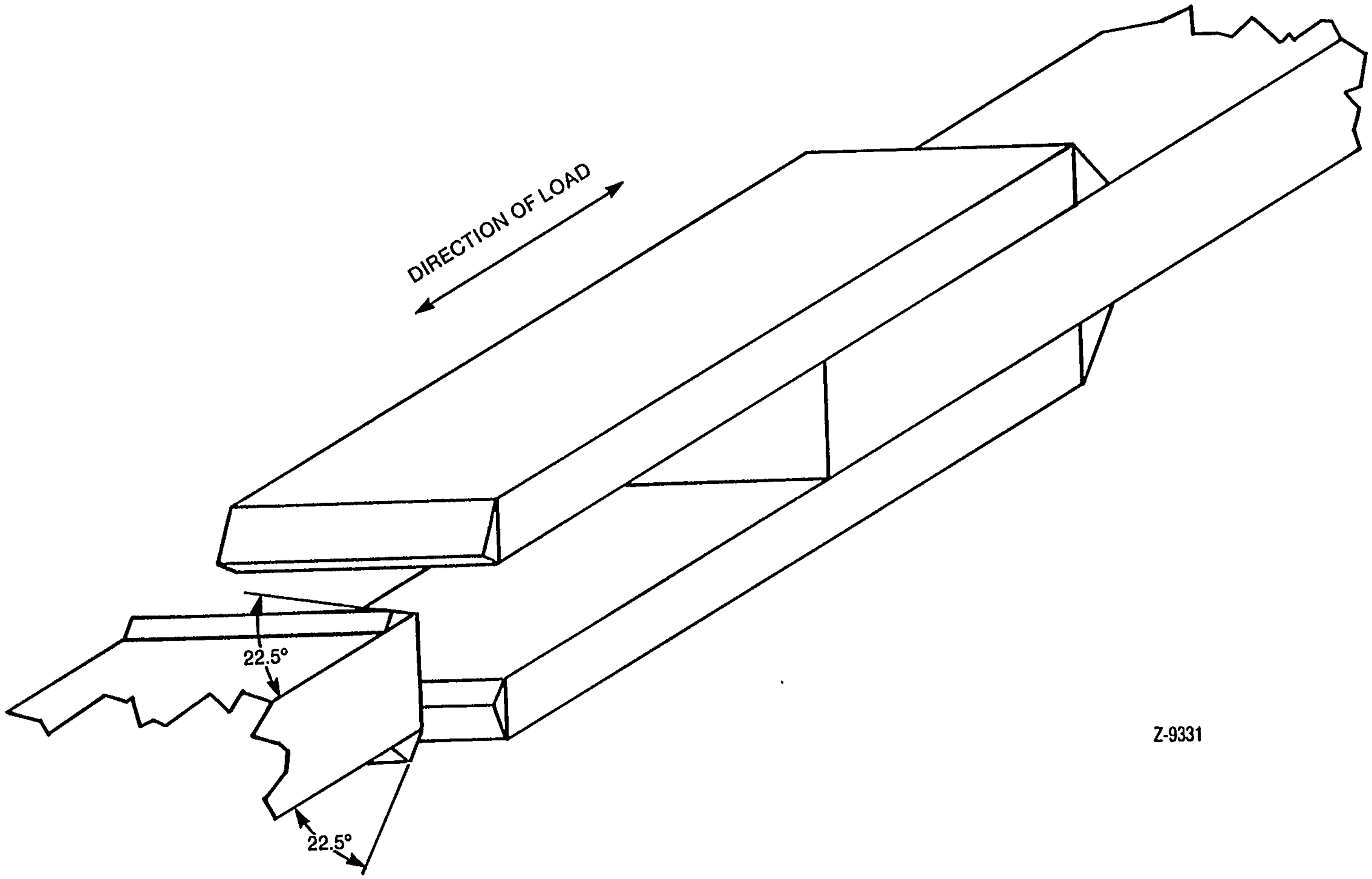


Figure 6. Typical Transverse Shear Failure Angle

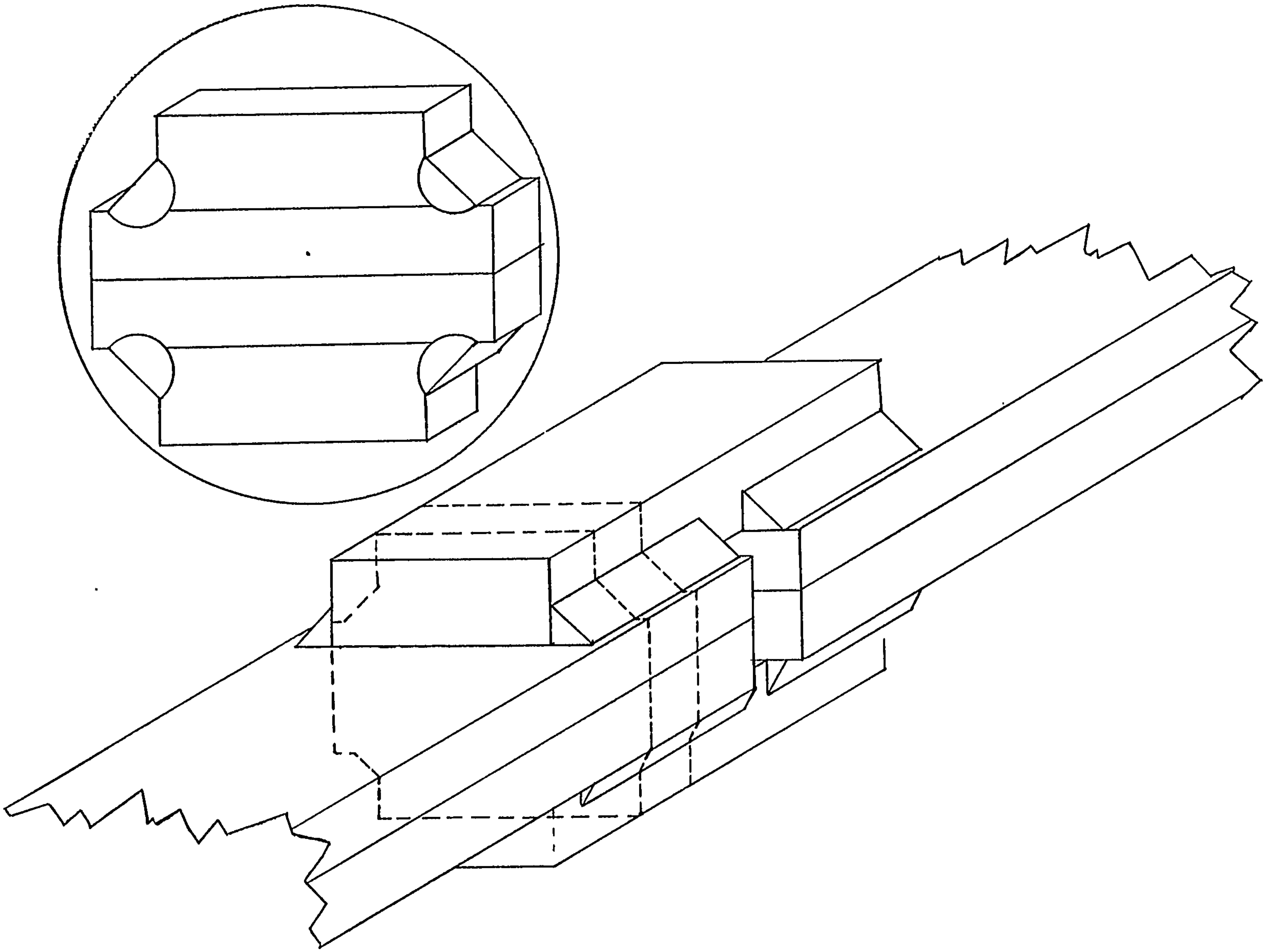


Figure 7. Typical Cross-Section Used for Macroetch of Longitudinal Fillet Weld Test Specimen

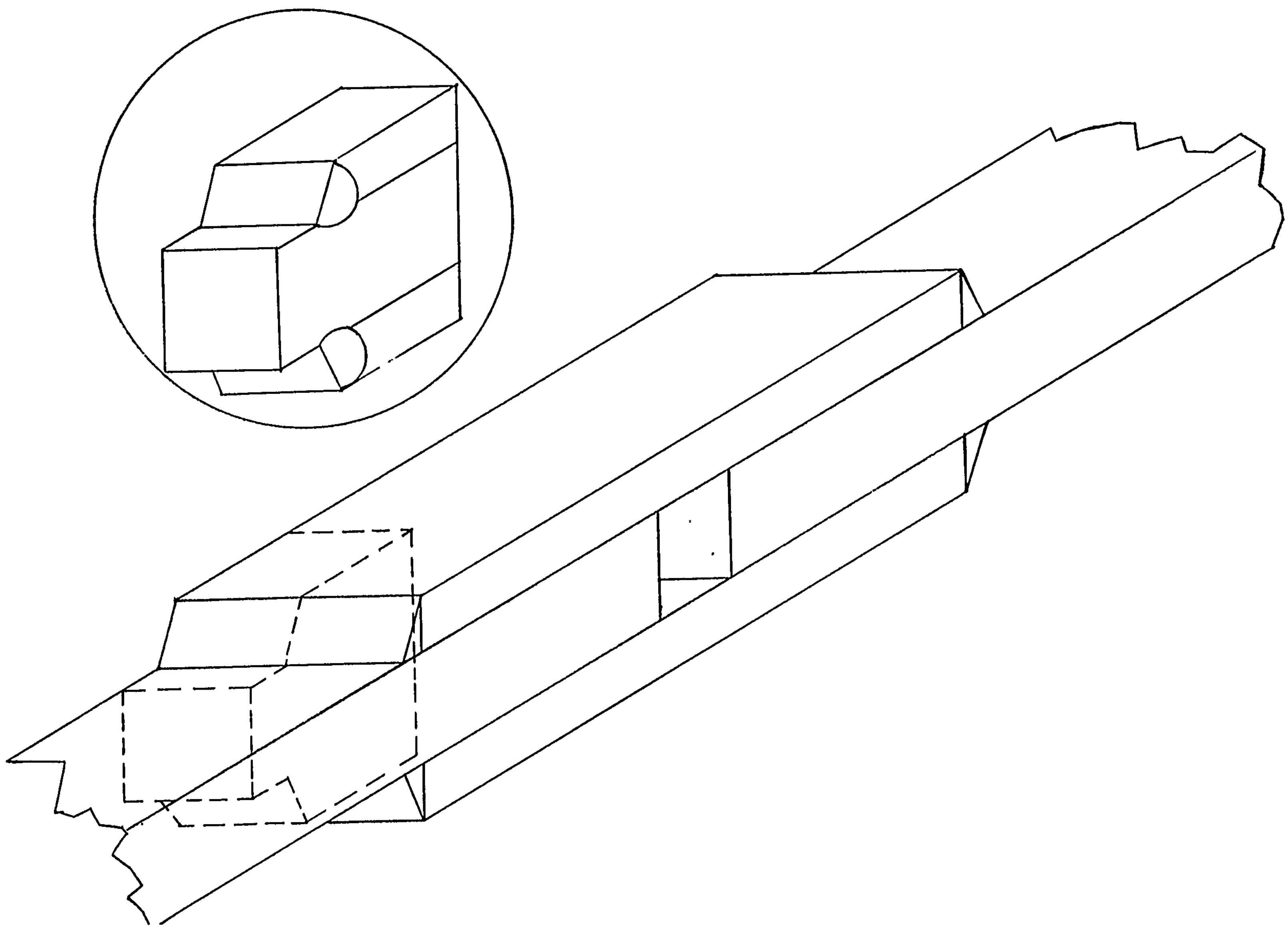


Figure 8. Typical Cross-Section Used for Macroetch of Transverse Fillet Weld Test Specimen

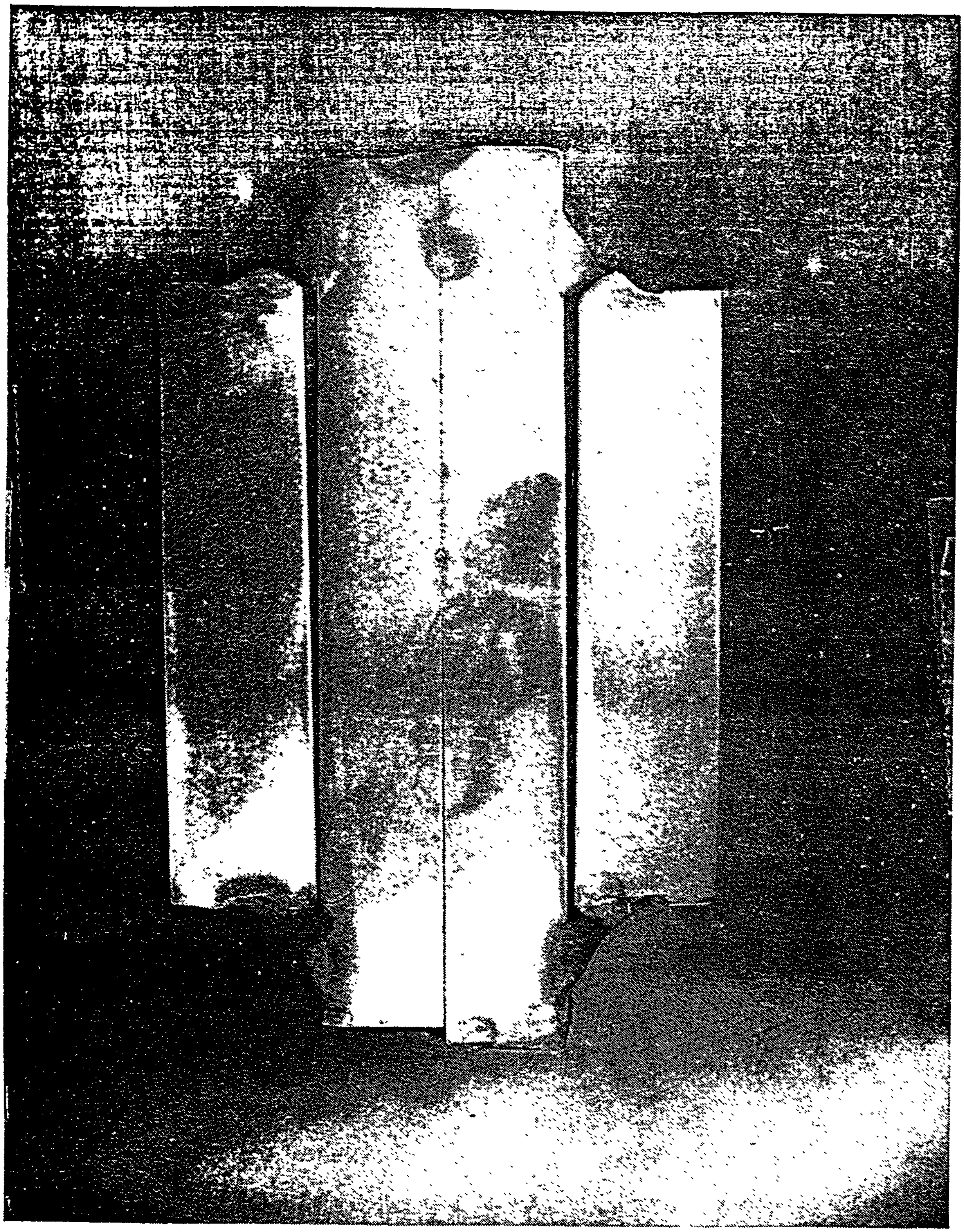


Figure 9. Longitudinal Shear Test Specimen 1A

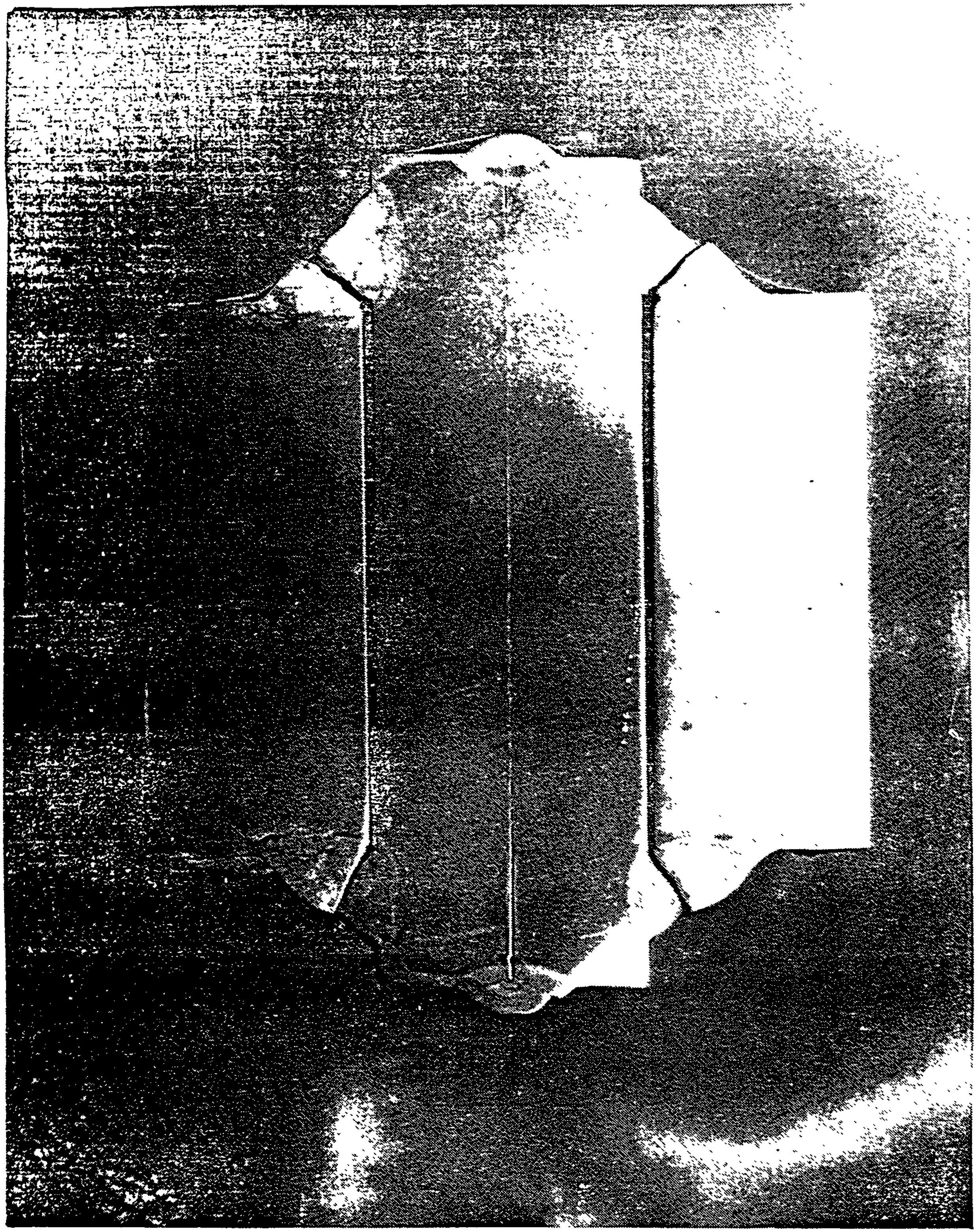


Figure 10. Longitudinal Shear Test Specimen 15A

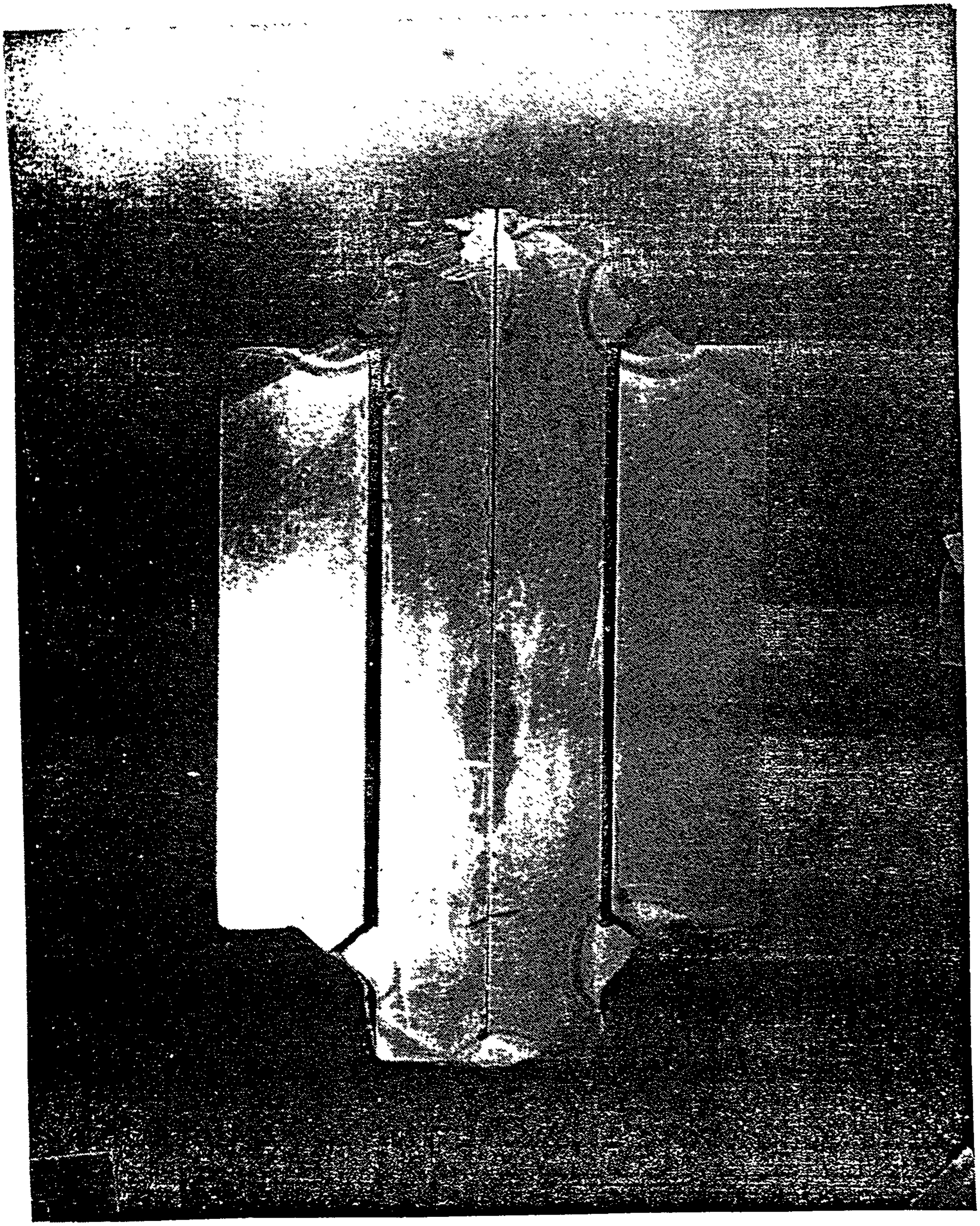


Figure 11. Longitudinal Shear Test Specimen 21A

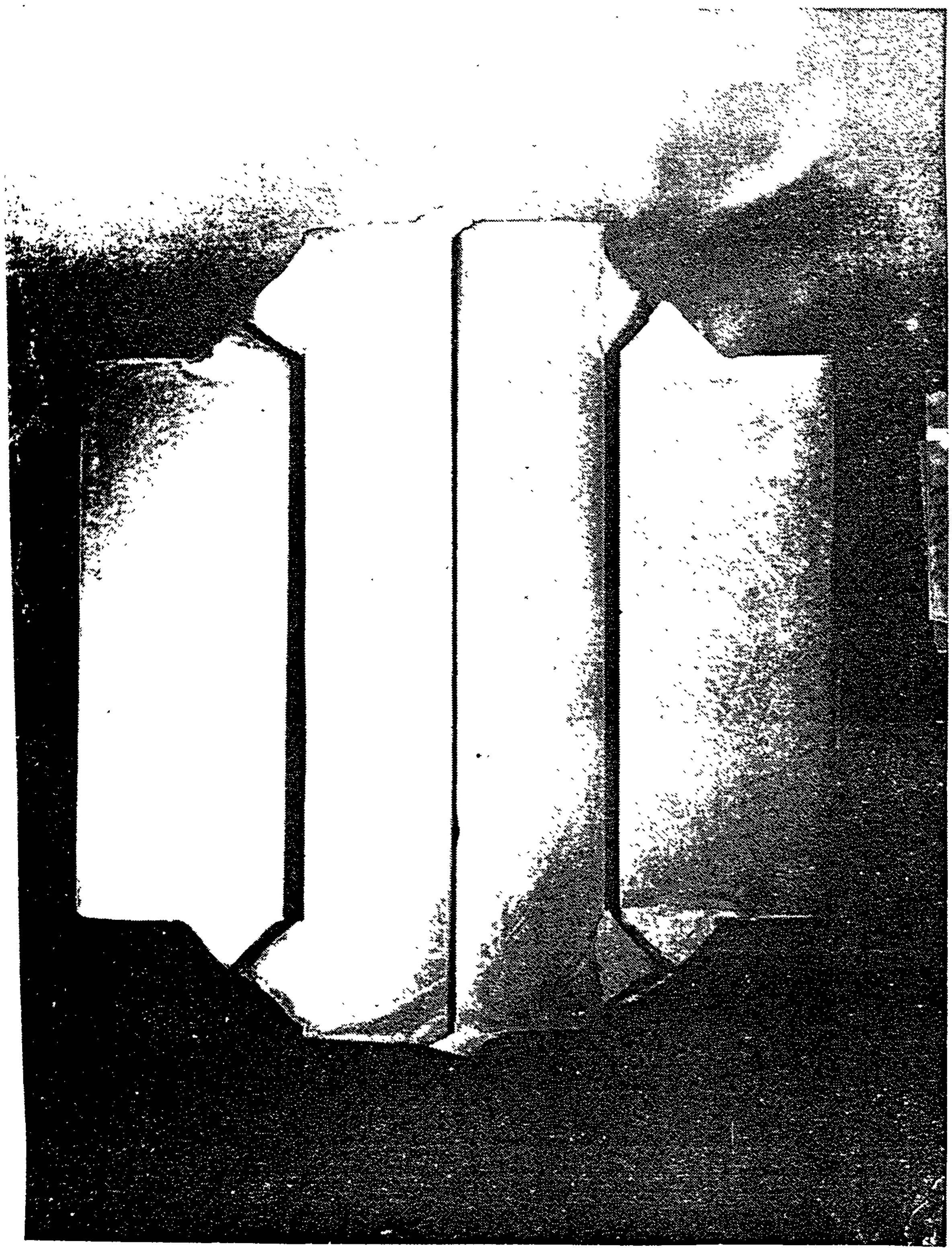


Figure 12. Longitudinal Shear Test Specimen 27A

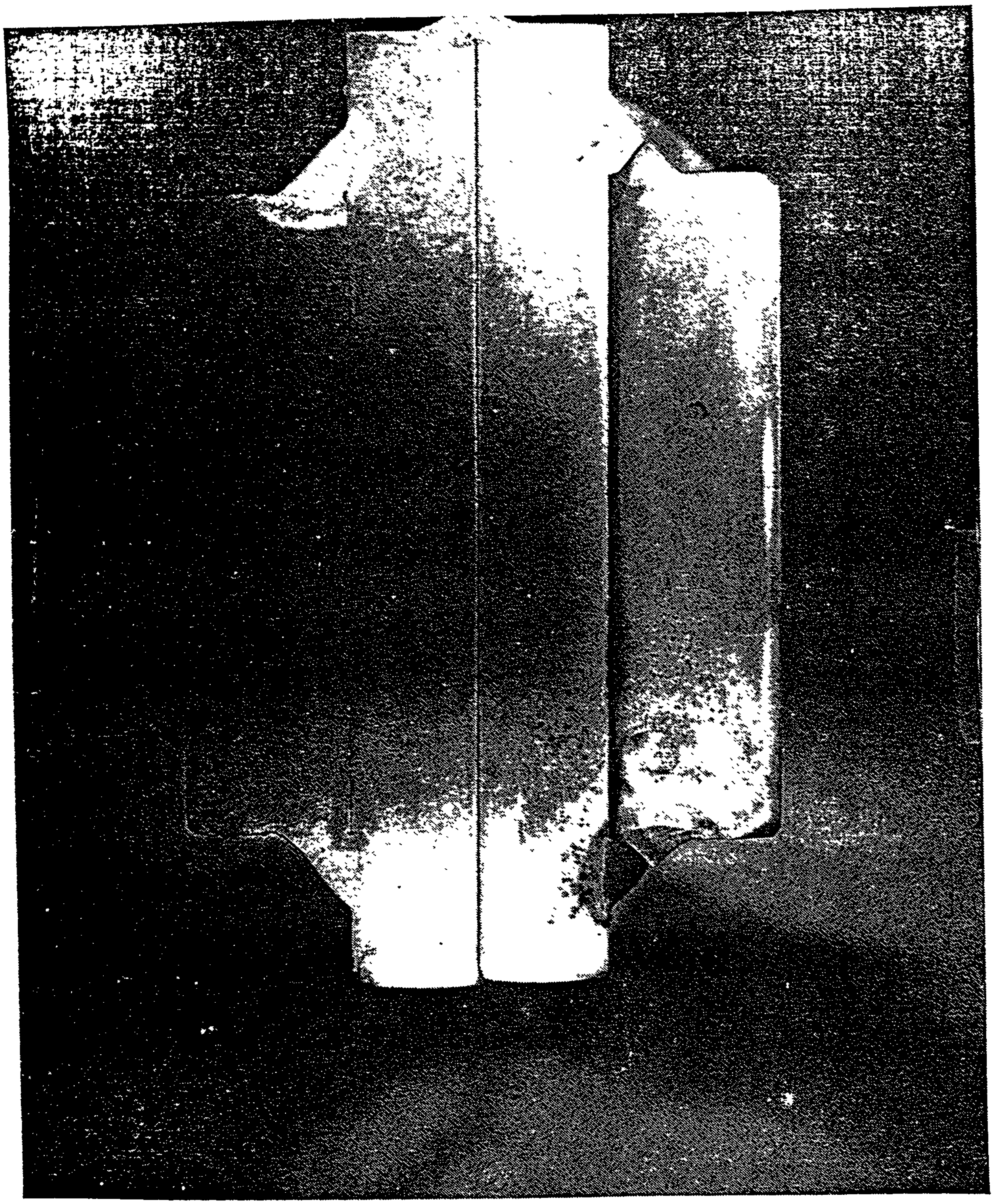


Figure 13. Longitudinal Shear Test Specimen 35A

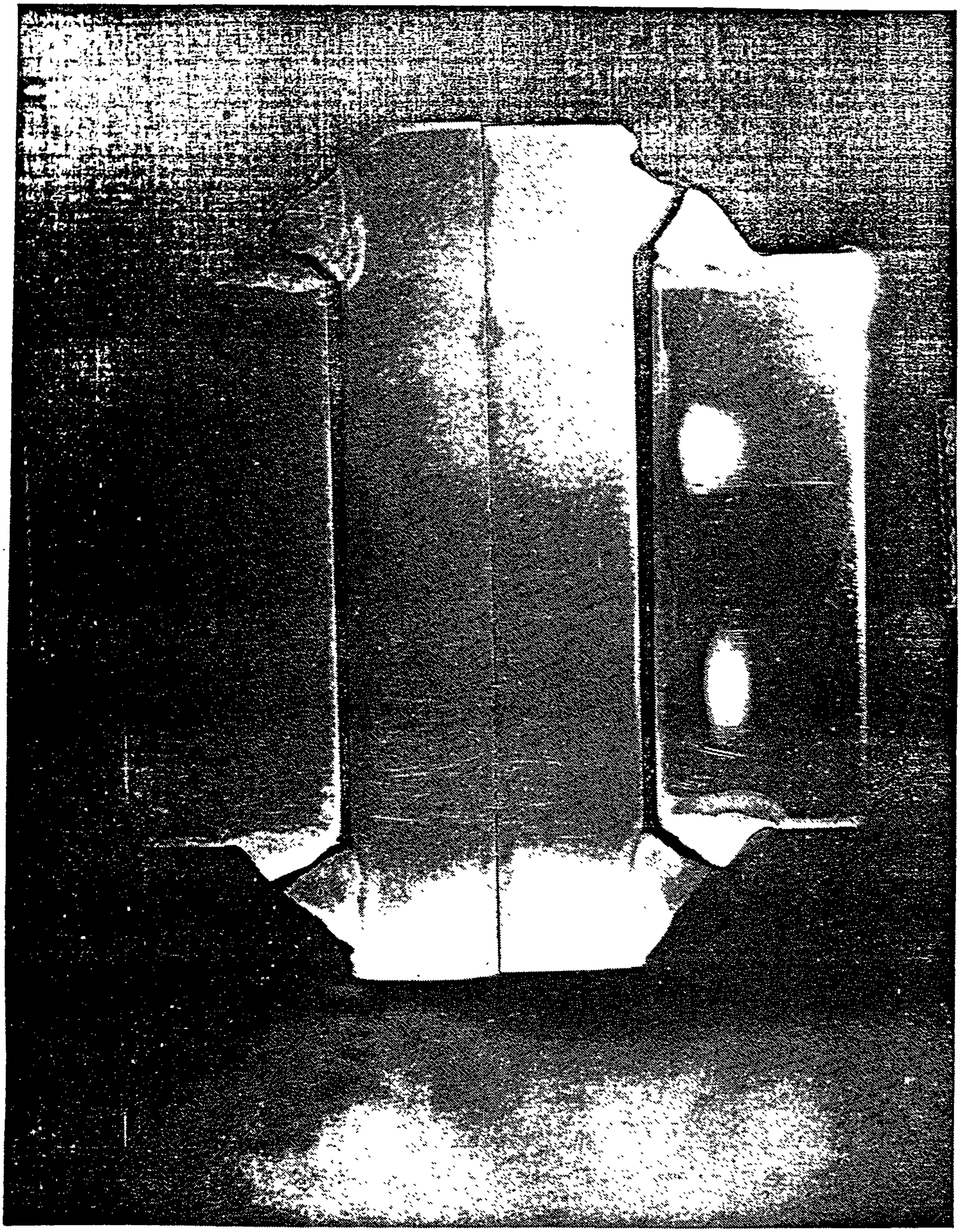


Figure 14. Longitudinal Shear Test Specimen 45A

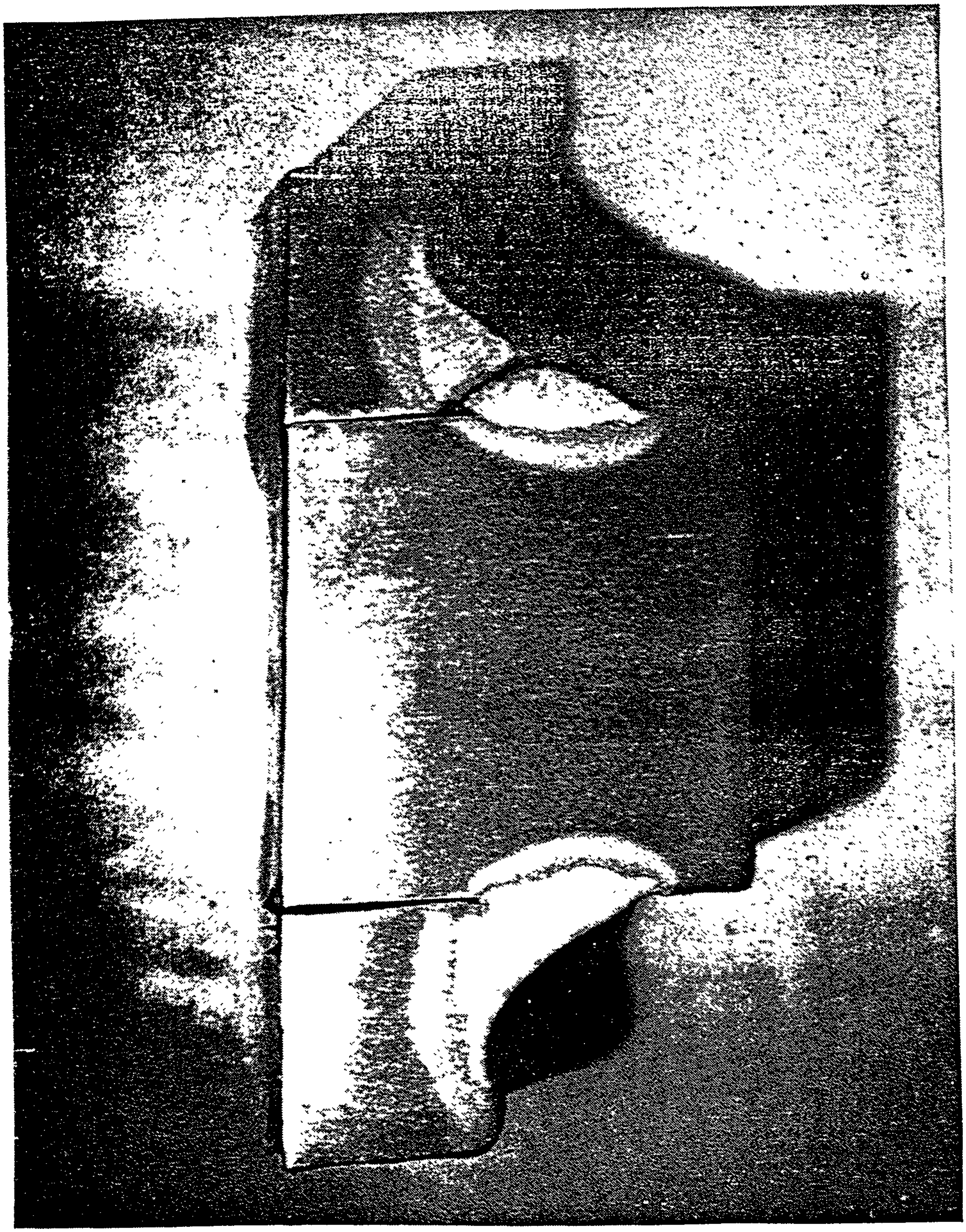


Figure 15. Transverse Shear Test Specimen lB

Figure 16. Transverse Shear Test Specimen 15B

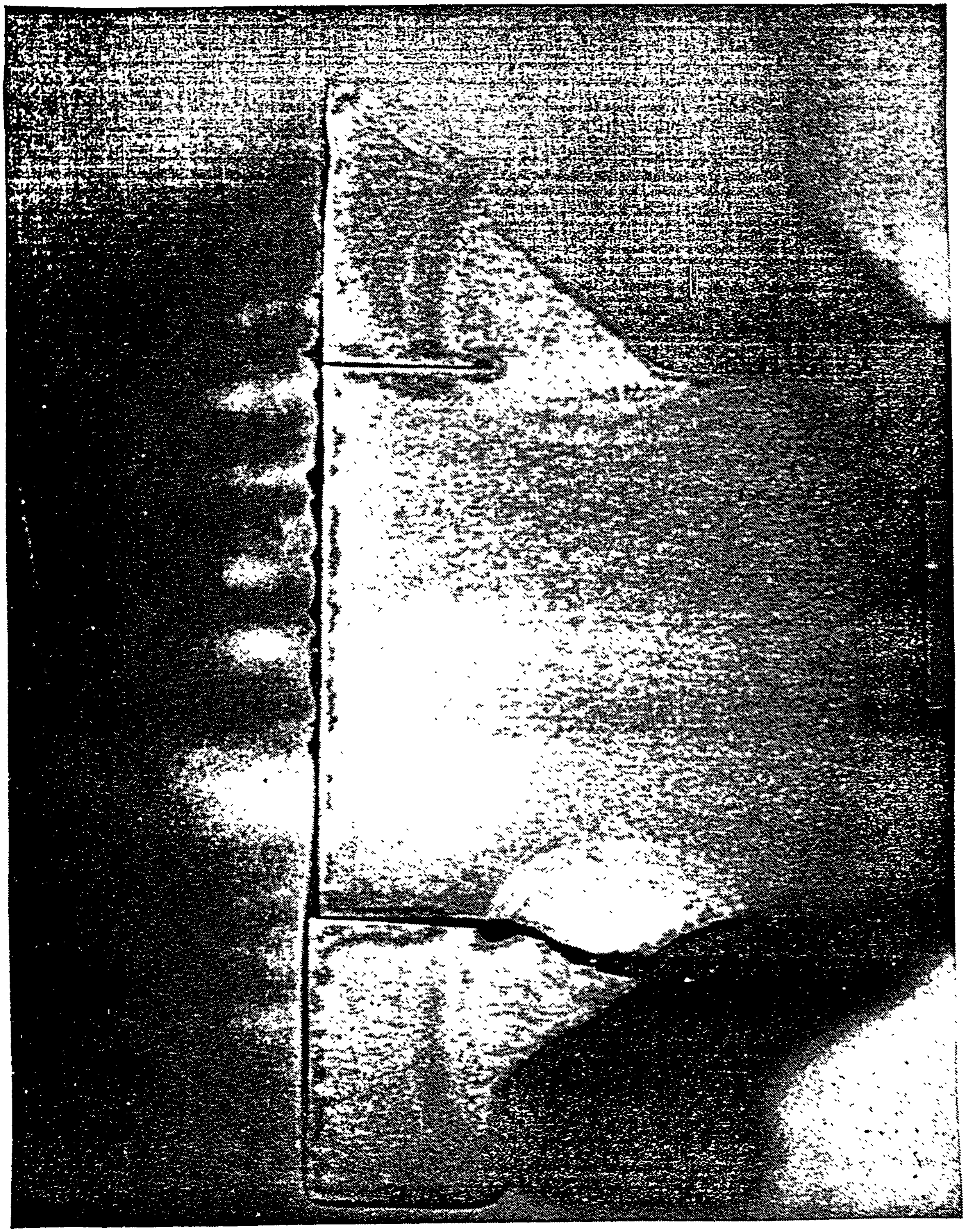


Figure 17. Transverse Shear Test Specimen 21B

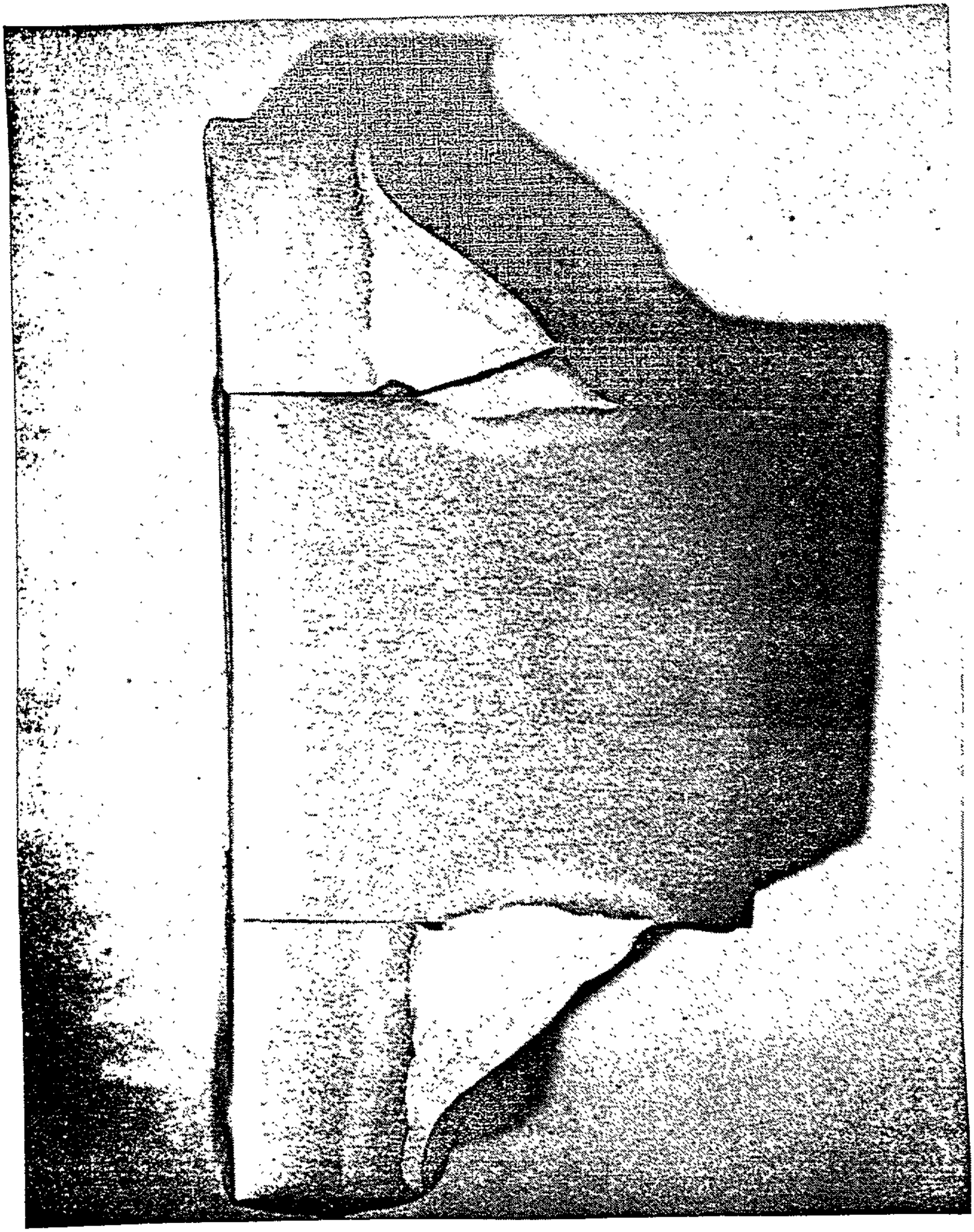


Figure 18. Transverse Shear Test Specimen 25B

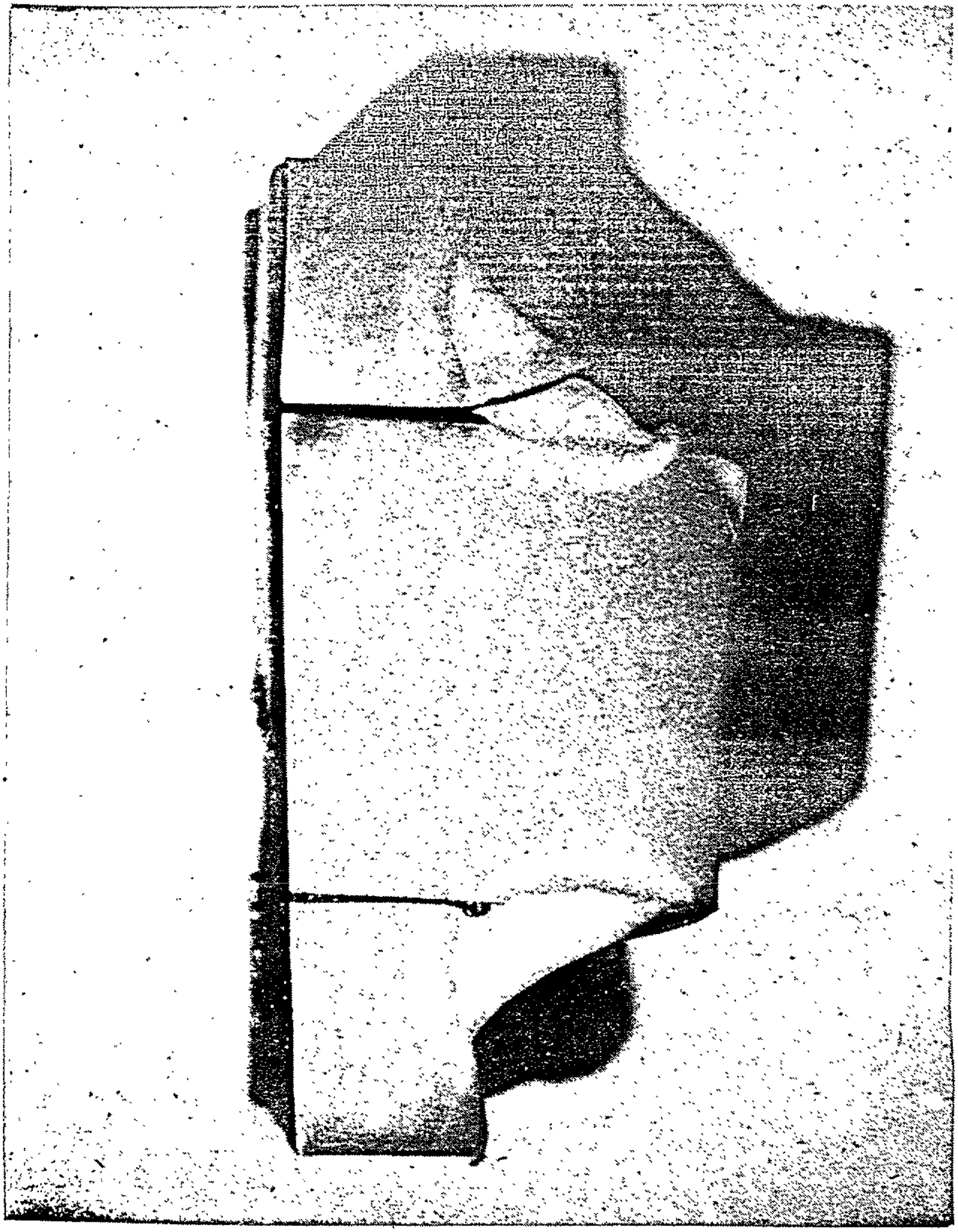


Figure 19. Transverse Shear Test Specimen 35B

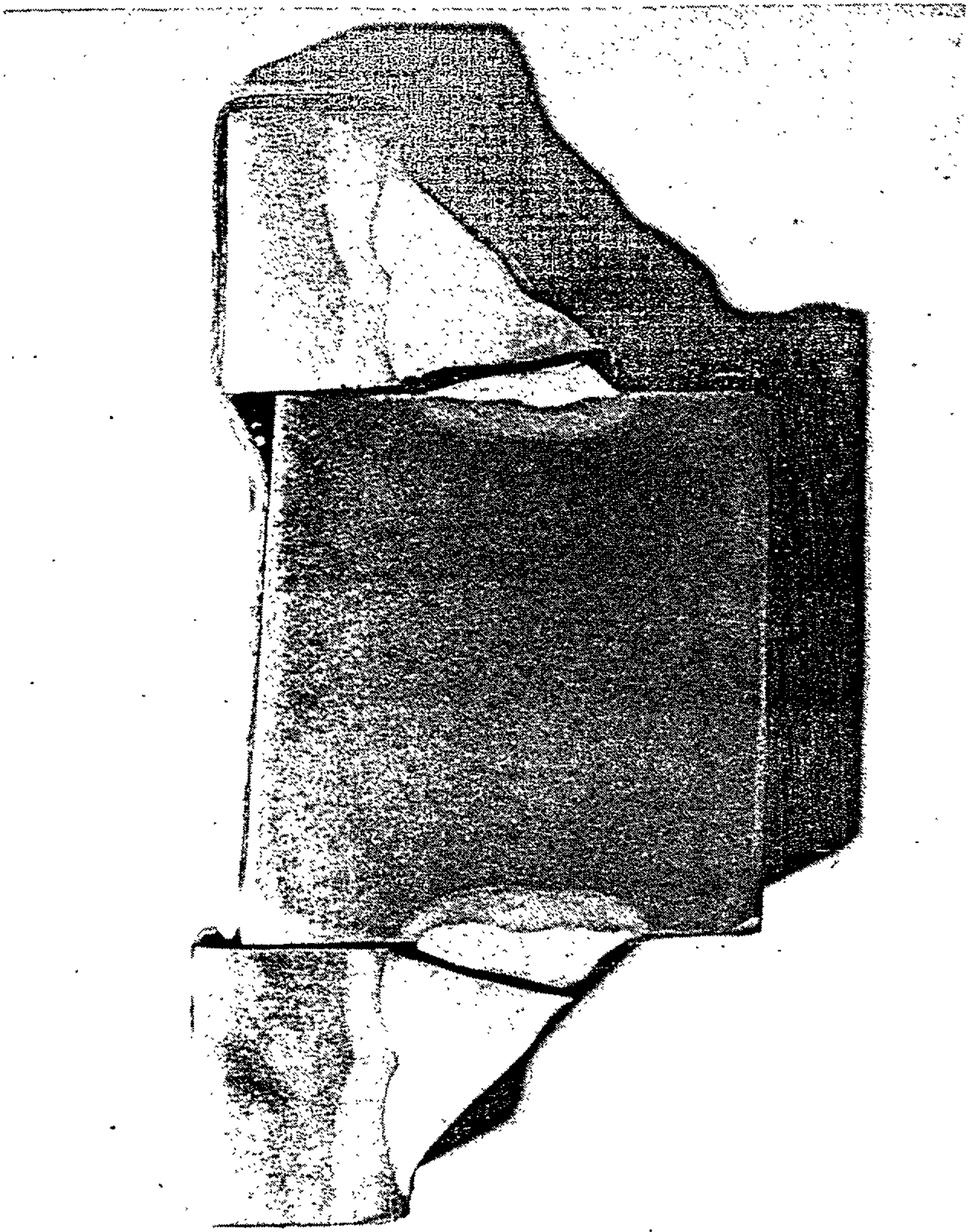


Figure 20. Transverse Shear Test Specimen 45B

IV. DISCUSSION

MIL-STD-1628 employs an array of efficiency charts to determine fillet weld sizes. Each chart is based on a computation factor, which is a function of the base material strength and weld metal shear strength. The computation factor is calculated using the following formula:

$$C_F = \frac{R_1}{1.414\ R_2}$$

R_1 = Ultimate Tensile Strength of Weaker Member (psi)

R_2 = Shear Strength of Weld Metal (psi)

MIL-STD-1628 specifies a longitudinal shear strength of 59 KSI (407 MPa) for MIL-70XX covered electrodes. The values for the MIL-71T1-HY electrodes, as shown in Table 8, averaged 68 KSI (476 MPa). Comparing the computation factors calculated with an R_1 (High Tensile Steel) value of 75 KSI (517 MPa), the SMAW and FCAW values are .90 and .75 respectively. Figures 21 and 22 are MIL-STD-1628 efficiency charts for these computation factors. A definite reduction in fillet weld size can be appreciated with the implementation of the MIL-71T1-HY data.

MIL-STD-1628 specifies a longitudinal shear strength of 87 KSI (600 MPa) for the MIL-11018-M[10] covered electrode and 83 KSI (572 MPa) for the MIL-100-1[11] bare electrode. However, as a result of recent shear testing[12] a potential revision to MIL-STD-1628 is proposed to reduce the MIL-11018-M covered electrode shear criteria to 79 KSI

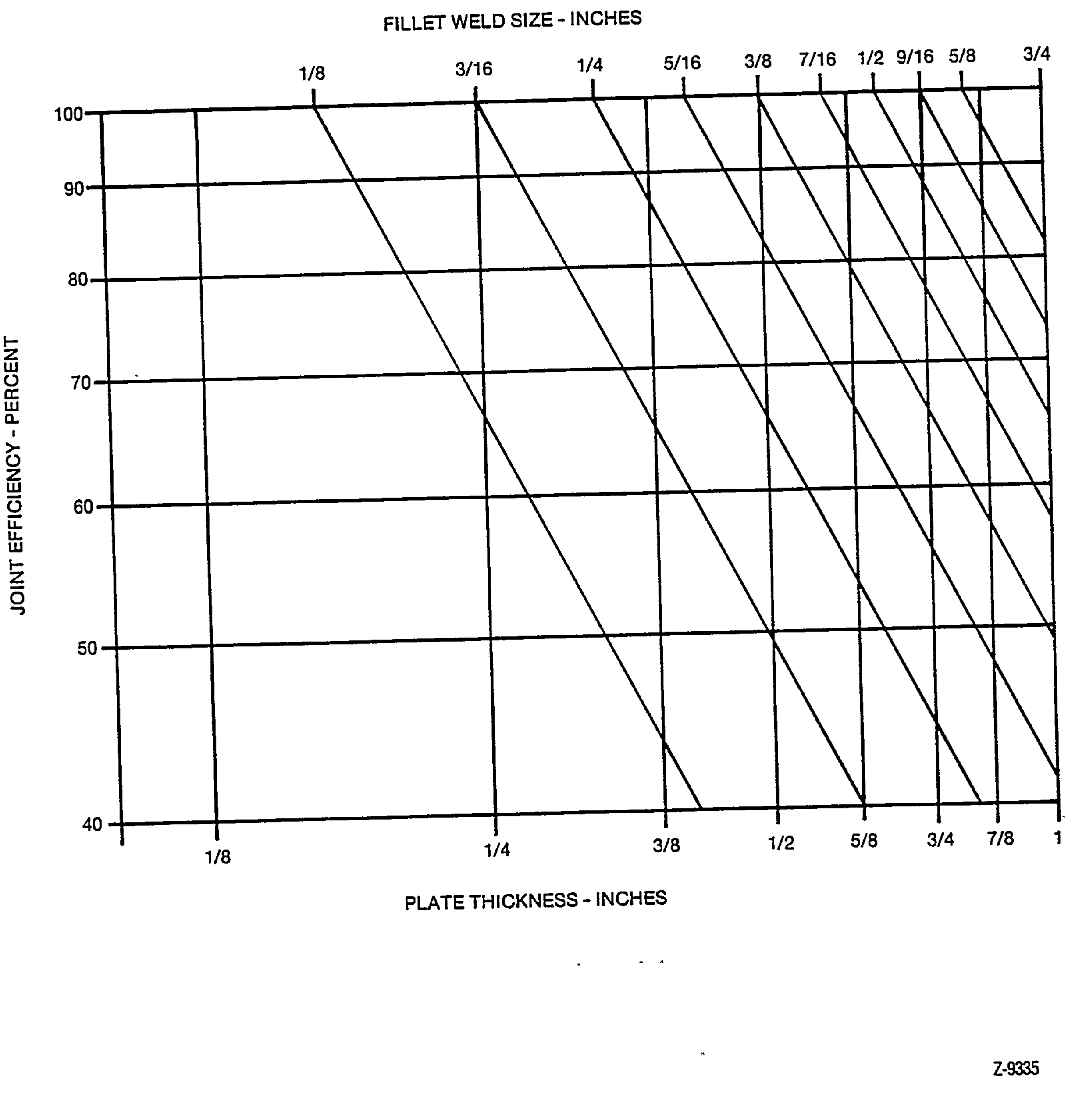


Figure 21. Efficiency Chart for Computation Factor 0.75

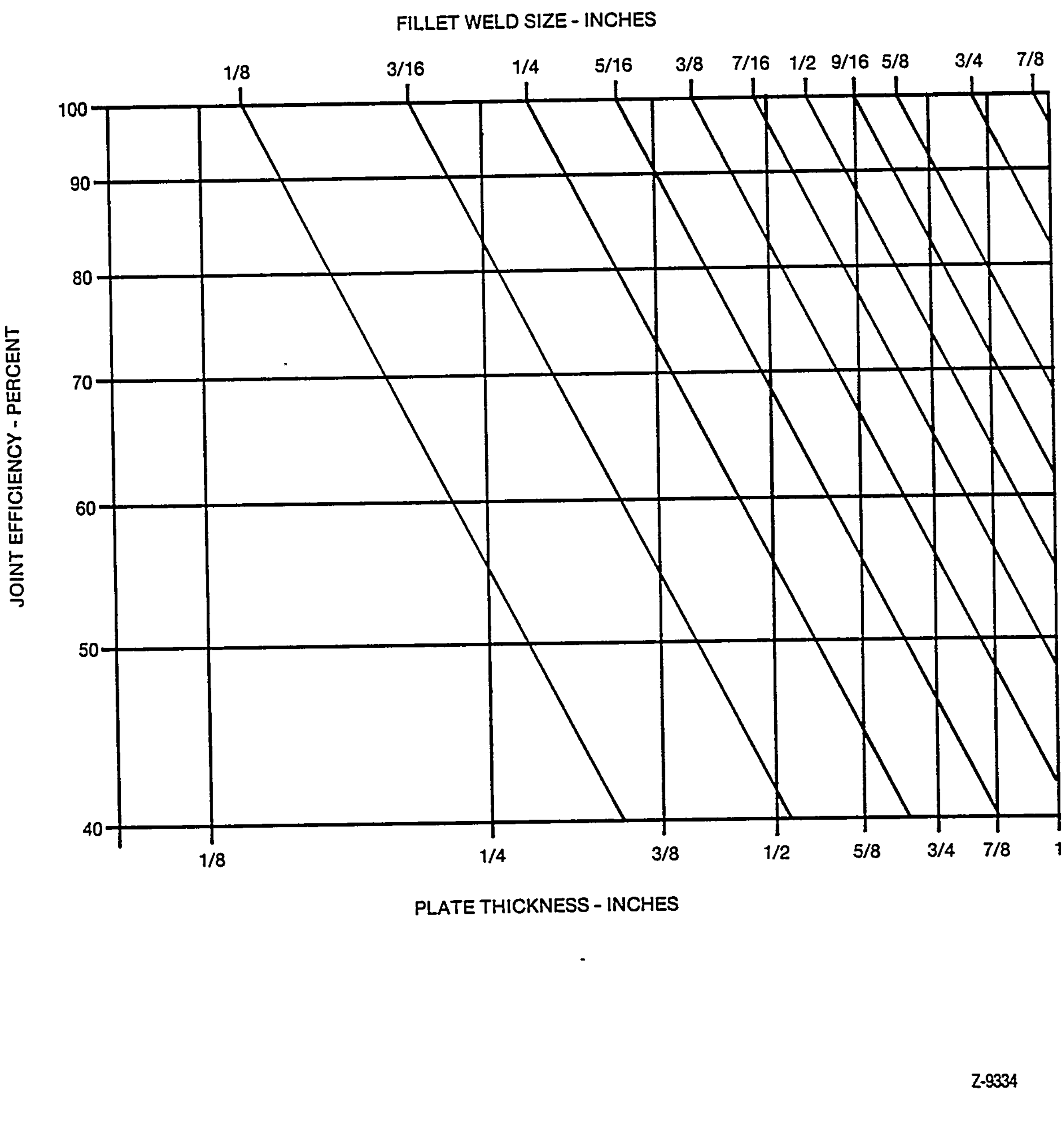


Figure 22. Efficiency Chart for Computation Factor 0.90

(545 MPa) and set the value for M1L-10018-M1 at 72 KSI (496 MPa). The values for the MIL-101-TC/TM electrodes as shown in Table 8 averaged above 74 KSI (510 MPa) providing strong support for a revision.

Another topic of discussion that arose during laboratory work concerned observations of the shear fractures that followed each test. A Vernier Caliper was used to measure the specimen's leg sizes and lengths. The legs of the fillet welds varied by more than 1/32" (1mm) on any one linear segment. making it difficult to measure with accuracy. Consequently, the throat dimensions used in the calculations of shear strength were in all cases based on the average measured length of fillet leg sizes.

Per ANSI/AWS B4.0-85, shear strength in pounds per square inches is determined by dividing the unit shear load in pounds per linear inch by the average theoretical throat dimensions of the sheared weld. To comply with this specification, a 45° shear failure is assumed for both longitudinal and transverse orientations. All practical and theoretical data[13] support a 45° angle for longitudinal failures. However, evaluation of failures from this project and theory from related studies confirm a 22.5° shear angle in transverse specimens. Assuming this to be valid, calculations with 22.5° would decrease the actual shear strength values for transversely welded fillets by 8%.

In an investigation to determine a theoretical method of obtaining shear strength in transverse fillet welded joints[14], a formula was derived to *show the strength relationships between longitudinal and transverse fillet welds. The theory indicated that the failure path would follow a 22.5° transverse shear angle. Many observations corroborated that theory. The formula stated that transverse shear strengths were 46% greater than the longitudinal. In comparison, data from this project produced transverse shear values 40% greater than longitudinal in welds made with MIL-71T1-HY electrode. A 28% greater strength was produced with the MIL-101-TCITM electrode. Slight differences in a fillet weld's adjacent leg lengths would change the shear angle to anything but a perfect 22.5°. This and inaccuracies in weld measurements may account for the conflict between practical and theoretical results.*

A major objective of this project was to determine if the increased depth of penetration produced by FCAW would have a beneficial effect on a weldts shear strength. Evaluation of shear failures and macro etches (Figures 9 through 20) of both longitudinal and transverse specimens did not provide strong evidence to support this theory. The metallography shows that the welding parameters used throughout the project do not produce a significant amount of increased penetration in comparison to a similar SMAW deposit. As a result, this data cannot support a definitive answer to the question of depth of penetration and its affect on shear strength.

V. <u>*CONCLUSIONS*</u>

The shear strength of fillet welds produced by MIL-71T1-HY is 15% higher than the comparable MIL-70XX SMAW electrode. With the implementation of this data, efficiency tables from MIL-1628 with lower computation factors may be used, thus reducing fillet weld sizes.

As a result of recent shear testing, a potential revision to MIL-STD-1628 may set the longitudinal shear value for MIL-10018M1 at 72 KSI (496 MPa) and decrease the MIL-11018M covered electrode criteria to 79 KSI (545 MPa). The FCA W electrode, MIL-101-TC/TM evaluated in this study, produced 74 KSI (510 AdPa), thus supporting the accuracy of these proposed revisions.

The fillet welds tested in this project and related shear studies support a transverse shear failure angle of 22.5°. Empirical observations of this angle indicate a need for a change in the analytical method set forth in AIVSI/AWS B4.0-85 of calculating transverse shear strengths.

Evaluating shear failures and macro etches of both longitudinal and transverse specimens produce no evidence that penetration was responsible for increased shear strength. The welding parameters used throughout the project did not produce a significant amount of increased penetration in comparison to a similar SMAW deposit. As a result, the data presented does not purport to answer the question of penetration and it's affect on shear strength.

VI. RECOMMENDATIONS

The U. S. Navy should consider revising Table 11 of MIL-STD-1628 to include the results of the MIL-71T1-HY and MIL-101TC/TM shear testing as follows:

FILLER METAL TYPE	MINIMUM ULTIMATE TENSILE STRENGTH (KSI)	AVERAGE LONG SHEAR STRENGTH (KSI)	DOUBLE FILLET WELD AVERAGE SHEAR STRENGTH PER LINEAR INCH OF CONTINUOUS WELD (KLI) — FILLET WELD SIZE (INCH)								
			1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8
MIL-71T1-HY	70	68	12	18	24	30	36	42	48	54	60
MIL-10ITC/TM	100	74	13	20	26	33	39	36	52	59	65

Contracts invoking this specification will benefit from the lower computation factors and potentially smaller fillet welds.

The formula for determining fillet weld shear strength under Section 9 of ANSI/AWS B4. 0-85 (Standard Methods for Mechanical Testing of Welds) assumes a 45° theoretical throat dimension. Theoretical and practical test results from this and related projects suggests a 22.5° shear angle for transverse shear failures. In view of this information the American Welding Society should consider a revision and or clarification to this specification.

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2. *MIL-E-24403/lD, Type MIL-71TI-HY*

3. *MIL-E-24403/2A, Type MIL-101-TC/TM*

4. *MIL-S-16216, Steel Plate, Alloy. Structural, High yield Strength (Hy-80 and HY-100)*

5. *MIL-S-24645, Steel Plate, Sheet, or Coil, Age Hardening Alloy, Structural, High Yield Strength (HSLA-80)*

6. *MIL-E-22200/10A, Type MIL-7018-M*

7. *MIL-E-22200/10A, Type MIL-10018-M1*

8. *Standard Methods for Mechanical Testing of Welds, ANSI/AWS B4.0-85, Pages 39-42*

9. *MIL-S-22698, Type AH* 36 *or DH 36*

10. *MIL-E-22200/lF, MIL-11018-M*

11. *MIL-E-23765/2C, MIL-100S-1*

12. *Mare Island Naval Shipyard, Technical Report 138-4-80, Revision A, December 1980*

13. *Welding Kaiser Aluminum, page 3-35, Kaiser Aluminum and Chemical Sales, 1967*

14. *Kate, B. and Morita, K., Strength of Transverse Fillet Welded Joints, Welding Journal, Welding Research Supplement, February 1974, Pages 59s-64s*